

IN-DEPTH FILM GUIDE

DESCRIPTION

In *The Biology of Skin Color* (<http://www.hhmi.org/biointeractive/biology-skin-color>), Penn State University anthropologist Dr. Nina Jablonski walks us through the evidence that the different shades of human skin color are evolutionary adaptations to the varying intensity of ultraviolet (UV) radiation in different parts of the world. Our modern human ancestors in Africa likely had dark skin, which is produced by an abundance of the pigment eumelanin in skin cells. In the high-UV environment of sub-Saharan (or equatorial) Africa, darker skin offers protection from the damaging effects of UV radiation. Dr. Jablonski explains that the variation in skin color that evolved since some human populations migrated out of Africa can be explained by the trade-off between protection from UV and the need for some UV absorption for the production of vitamin D.

KEY CONCEPTS

- A. Biological traits are not inherently good or bad. Some traits can provide an advantage to an organism in certain environments but be a disadvantage in other environments.
- B. Inherited traits that provide a survival and reproductive advantage in a particular environment are more likely to be passed on to the next generation and thus become more common over time.
- C. Different human populations living many generations in a particular part of the world may have different variations in certain traits. In spite of these differences, all humans are very closely related and share most traits.
- D. Evidence from different disciplines, such as anthropology, developmental biology, physiology, genetics, and cell biology, can inform what makes a human trait beneficial or harmful in a particular environment.
- E. Variations in genes can lead to differences in biological traits. By studying the DNA sequences of large numbers of people from different populations, scientists can estimate when and where those variations arose.
- F. Evolution involves trade-offs; a change in a gene that results in an adaptation to one aspect of the environment may be linked to a disadvantage with respect to another aspect of that same environment.
- G. Cells in multicellular organisms specialize to meet particular functions in an individual.
- H. Molecules in living organisms absorb or reflect certain wavelengths of light from the sun. When a molecule absorbs light, the energy is transformed into other forms of energy.

CURRICULUM AND TEXTBOOK CONNECTIONS

Curriculum	Standards
NGSS (April 2013)	MS-PS4-2, MS-LS-1, MS-LS-2, MS-LS3-1, MS-LS4-4 HS-LS3-1, HS-LS4-1, HS-LS4-4
AP Biology (2012–2013)	1.A.1, 1.A.2, 1.A.4, 1.C.3, 3.A.1, 3.C.1, 4.C.1, 4.C.2
IB Biology (2016)	1.2, 5.1, 5.2, 6.3

Textbook	Chapter Sections
Miller and Levine, <i>Biology</i> (2010 ed.)	14.1, 16.3, 16.4, 17.1, 17.2, 26.3, 32.3
Reece et al. <i>Campbell Biology</i> (10th ed.)	14.3, 17.5, 23.1, 23.3, 23.4

PRIOR KNOWLEDGE

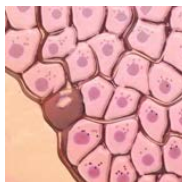
Students should

- be familiar with the tree of life and know that humans are part of the primate group and that chimpanzees are our species' closest living relative,
- know that modern humans evolved in Africa and then migrated throughout the world, and
- know that scientists have methods to analyze and compare DNA from different individuals within species and across species.

PAUSE POINTS

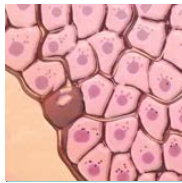
The Biology of Skin Color (<http://www.hhmi.org/biointeractive/biology-skin-color>) may be viewed in its entirety or paused at specific points to review content with students. The table below lists suggested pause points, indicating the beginning and end times in minutes in the film.

	Begin	End	Content Description	Review Questions	Standards
1	0:00	3:54	<ul style="list-style-type: none"> • Biological traits aren't good or bad. They are features that have evolved within populations because they enhance an organism's odds of surviving and passing on its genes. • Skin color is an easily visible marker of variability. Our lack of 	<ul style="list-style-type: none"> • Can you think of other traits that are highly variable like human skin color? • What is an adaptation? • What is the connection between DNA and visible traits? 	<p>NGSS (2013) MS-LS4-4, HS-LS3-1, HS-LS4-1, HS-LS4-4</p> <p>AP Biology (2012–13) 1.A.1, 1.A.2, 1.A.4, 3.A.1, 4.C.1, 4.C.2</p> <p>IB Biology (2016) 1.2, 6.3, 5.2</p>



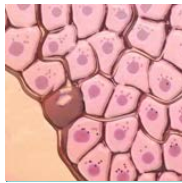
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			<p>body hair and our variable skin color are some of the traits that set us apart from our closest primate relatives.</p> <ul style="list-style-type: none"> • Wavelengths of light are reflected or absorbed by pigment in the skin called melanin. Melanin is synthesized in structures called melanosomes that are produced by cells called melanocytes. • There are two primary types of melanin in humans: pheomelanin, which is reddish yellow, and eumelanin, which is brown black. 		
2	3:55	9:07	<ul style="list-style-type: none"> • UV radiation can penetrate living cells and cause mutations in DNA. • Melanin protects human cells from the damaging effects of UV radiation by absorbing UV. • There is a clear correlation between the intensity of UV radiation and latitude. UV radiation is most intense along the equator and is weakest at the poles. • UV intensity predicts the skin color of indigenous populations. Stronger UV radiation is correlated with darker skin color. • Data suggest that variation in human skin melanin production arose as different populations adapted biologically to different solar conditions around the world. 	<ul style="list-style-type: none"> • What is a mutation? • Dr. Zalfa Abdel-Malek says that the supernuclear caps formed by melanin are like “little parasols.” Parasols are a type of umbrella. Explain this analogy. • The enzymes to produce melanin are found in all major taxa of life. What does this suggest about the importance of melanin production for living things? • Why do areas of high altitude (e.g., on the Tibetan plateau) have greater than expected UV intensity and areas of constant cloud cover (e.g., Congo Basin) have less than expected? • What does “indigenous” mean? • Why is it important when sampling human skin color to know whether an individual is indigenous or not? 	<p>NGSS (2013) MS-PS4-2, MS-LS3-1, MS-LS4-2, HS-LS1-1, HS-LS3-1, HS-LS3-2, HS-LS4-1, HS-LS4-2, HS-LS4-4</p> <p>AP Biology (2012–13) 1.A.1, 1.A.2, 1.A.4, 3.A.1, 3.C.1, 4.C.2</p> <p>IB Biology (2016) 1.2, 5.1, 5.2</p>



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3	9:08	13:32	<ul style="list-style-type: none"> • Early in human history, our ancestors lost most of their body hair and increased melanin production in skin. • Evidence of natural selection can be found in the genome. • <i>MC1R</i> is a gene that codes for a protein involved in the production of eumelanin. • Worldwide human genome sampling revealed that among African populations, the vast majority of individuals have an <i>MC1R</i> allele that results in darker skin. • Fossil and genetic evidence suggest that all humans were dark-skinned about 1.2 million years ago. • UV breaks down circulating folate in the skin's blood vessels. 	<ul style="list-style-type: none"> • Other primates have pale skin. Why isn't this a disadvantage to primates other than humans living in areas with intense UV radiation? • What did scientists infer from the lack of variation in the <i>MC1R</i> gene among African populations? • Melanin protects individuals from skin cancer. What is it about the timing of skin cancers that may decrease their importance in causing the evolution of dark skin color? 	<p>NGSS (2013) MS-LS4-2, MS-LS4-4, HS-LS1-1, HS-LS3-1, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4</p> <p>AP Biology (2012–13) 1.A.1, 1.A.2, 1.A.4, 3.A.1, 3.C.1, 4.C.2</p> <p>IB Biology (2016) 5.1, 5.2</p>
4	13:33	18:57	<ul style="list-style-type: none"> • UV-B absorption is critical for the synthesis of vitamin D, a process that starts in the skin. • Weaker UV-B intensity and greater UV-B variability throughout the year in areas toward the poles put dark-skinned individuals at risk for vitamin D deficiency. • Toward the poles, selective pressure for dark skin (to protect folate) decreases and selection for lighter skin shades (to enable vitamin D synthesis) increases. • Selection for light-skin gene variants occurred multiple times in different groups around the world. • Today, human migration does not take generations. So there is a lot of mismatch between skin color and geography. • Skin color is a flexible trait that is inherited independently of other traits. 	<ul style="list-style-type: none"> • Darker skin protects skin cells from UV radiation. So why aren't all humans dark skinned? • Indigenous peoples with diets rich in vitamin D living in high latitudes have dark skin. How does this observation support the hypothesis presented in the film about the selective pressure for the evolution of lighter skin? What other explanations could account for this observation? • What are the risks associated with light skin in equatorial areas? With dark skin in high latitudes? 	<p>NGSS (2013) MS-LS4-2, MS-LS4-4, HS-LS1-1, HS-LS3-1, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4</p> <p>AP Biology (2012–13) 1.A.1, 1.A.2, 1.A.4, 1.C.3, 3.A.1, 3.C.1, 4.C.2</p> <p>IB Biology (2016) 5.1, 5.2</p>



Short Film *The Biology of Skin Color*

BACKGROUND

"Melanin" is the collective term for a family of pigment molecules found in most organisms, from bacteria to humans, suggesting that melanin has a long evolutionary history and a broad range of important functions. In humans, melanin pigments are found mainly in human skin, hair, and eyes, and they include reddish-yellow pheomelanin and brown and black eumelanins. A related molecule called neuromelanin is found in brain cells.

In human skin, melanin pigments are synthesized in organelles called melanosomes that are found in specialized cells called melanocytes in the skin epidermis. Once the melanosomes are filled with a genetically determined amount and type of melanin, they migrate to other skin cells called keratinocytes.

Melanin synthesis involves a series of chemical reactions that begin with the amino acid tyrosine. An enzyme called **tyrosinase** promotes the conversion of tyrosine into DOPA, and then into dopaquinone. Dopaquinone can either be converted into eumelanin or combined with the amino acid cysteine to produce pheomelanin. Whether eumelanin or pheomelanin is produced depends partly on the activity of the **melanocortin 1 receptor (MC1R)** protein (**Figure 1**).

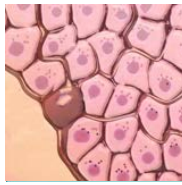
Eumelanin is a remarkable molecule that can absorb a wide range of the wavelengths of radiation produced by the sun, in particular, the higher-energy UV radiation. UV can damage biological molecules, including DNA. When UV radiation strikes eumelanin, the pigment absorbs the radiation and mostly transforms the energy into thermal energy, without breaking down, making it a powerful sunscreen that protects against UV damage. Pheomelanin is less effective as a sunscreen than eumelanin and can, in fact, produce damaging molecules, known as free radicals, when it interacts with UV radiation.

A person's skin color is determined primarily by the proportion of eumelanin to pheomelanin, the overall amount of melanin produced, and the number and size of melanosomes and how they are distributed. People with naturally darkly pigmented skin have melanosomes that are large and filled with eumelanin. Those with naturally paler skin have smaller and fewer melanosomes that contain varying amounts and kinds of eumelanin and the lighter-colored pheomelanin.

GENETICS OF MELANIN PRODUCTION

Constitutive pigmentation, or the pigmentation we are born with, is a polygenic trait, and many of the genes involved have been identified. These genes code for the enzymes that affect melanin synthesis and for the packaging, distribution, and degradation of melanosomes. Mutations in some of these genes cause an absence of melanin, as seen in human oculocutaneous albinisms and related disorders. For example, one form of albinism is caused by mutations that inactivate the tyrosinase gene.

The HHMI film mentions the importance of the *MC1R* gene. This gene codes for a protein that sits in the melanocyte membrane. It is activated by a variety of stimuli, such as by the **melanocyte-stimulating hormone (MSH)**, and is responsible for determining whether eumelanin or pheomelanin is produced. People of African descent have a version of the *MC1R* gene that is associated with eumelanin production. As mentioned in the film, there is very little variation in the *MC1R* gene in African populations, compared to populations indigenous to Europe and Asia. This lack of diversity at a genetic locus is evidence of selection,



suggesting that eumelanin production provides an advantage to people living in equatorial Africa. (Differences in the *MC1R* gene are also responsible for coat-color variations in the rock pocket mouse. For resources related to MC1R activity in this model system, search [BioInteractive.org](http://www.hhmi.org/biointeractive/), <http://www.hhmi.org/biointeractive/>, using the key words “MC1R” and “pocket mouse.”)

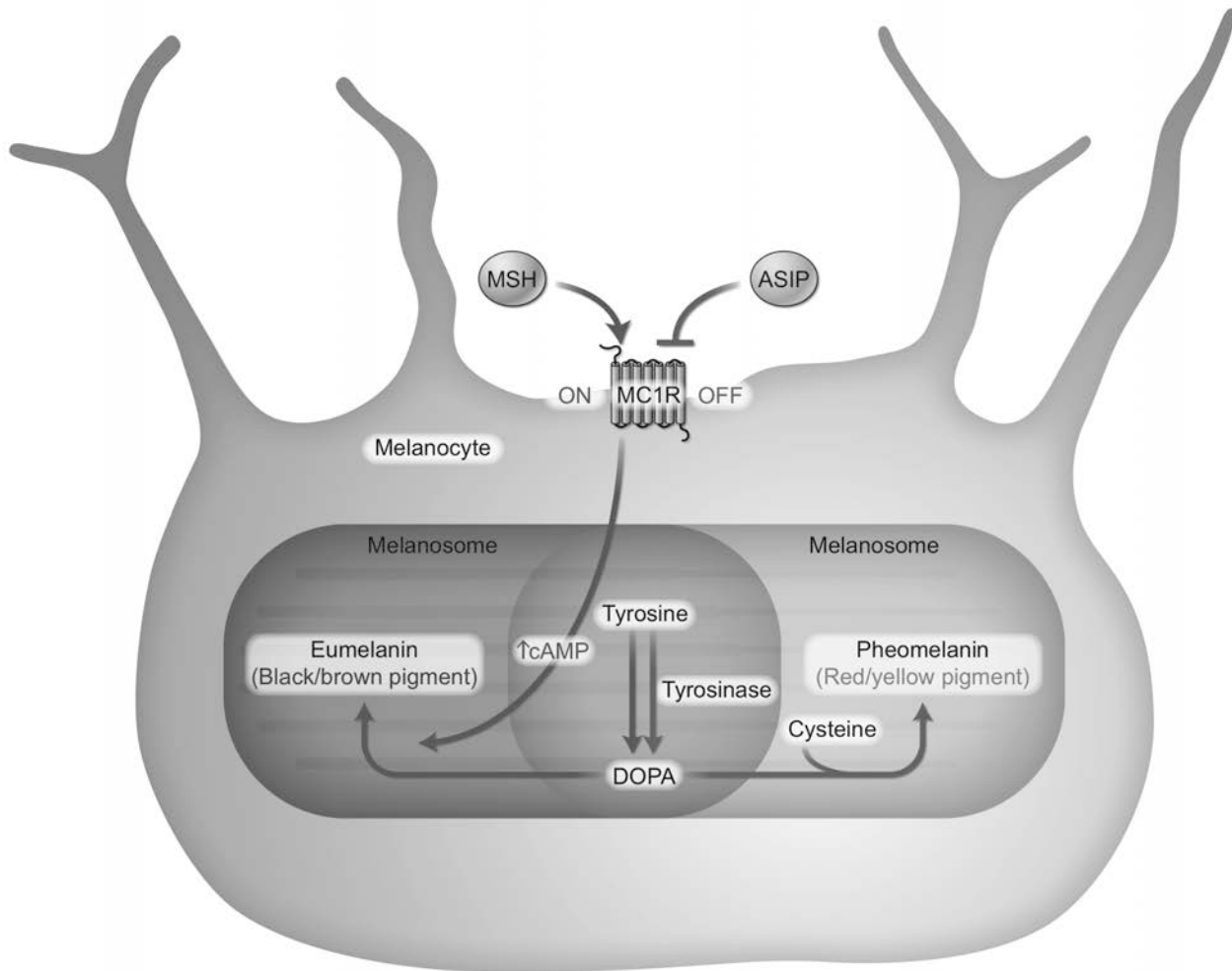
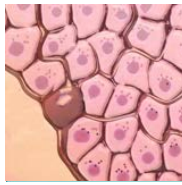


Figure 1. The melanin biosynthesis pathway. Melanin synthesis occurs in organelles called melanosomes and starts with the conversion of the amino acid tyrosine to DOPA by the enzyme tyrosinase. The melanosome sits inside a specialized skin cell called the melanocyte. A protein in the membrane of the melanocyte, called MC1R, receives messages from other cells. MC1R can be activated by the melanocyte-stimulating hormone (MSH), which is produced in response to damage by ultraviolet light (UVR) and other stimuli. Other molecules, such as the agouti signaling protein (ASIP), inhibit the activation of MC1R. When a functional MC1R is activated, it stimulates the production of cyclic adenosine monophosphate (cAMP), which is a second messenger important in transferring the effects of hormones into cells. This cAMP production in turn triggers a biochemical pathway that results in eumelanin production. Certain



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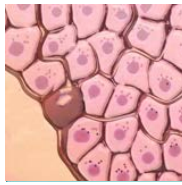
mutations in the *MC1R* gene that prevent MC1R activation or binding of ASIP and other inhibitors to MC1R result in pheomelanin production.

Scientists have looked for evidence of selection in other parts of the genome and have identified genes involved in skin color in different populations. For example, one allele of a gene called *OCA2* results in lighter skin colors and is almost exclusively found in East and Southeast Asian populations. On the other hand, alleles of two genes called *SLC24A5* and *SLC45A2* are also associated with lighter skin colors and are much more frequent in Europeans than in other populations. These and other data suggest that lighter skin color evolved more than once by different mechanisms. Interestingly, the *SLC24A5* and *SLC45A2* genes were first discovered in zebrafish and are responsible for differences in the stripe colors.

An important concept to make sure students understand is that genetic evidence indicates that similar skin colors and tanning abilities evolved independently as different human groups dispersed into distant places with similar UV conditions.

DISCUSSION POINTS

- *The Biology of Skin Color* film (<http://www.hhmi.org/biointeractive/biology-skin-color>) offers an opportunity to distinguish between negative and positive selection. Dr. Jablonski says that the lack of diversity among the *MC1R* alleles in people of equatorial African descent is due to negative selection. Tell your students that negative selection works to remove deleterious alleles from a population—another term that describes this is “purifying selection.” Then ask them to infer a definition for positive selection (selection for alleles that increase fitness). Positive selection results in directional selection. Positive selection for a beneficial allele can increase the frequency of neutral variants neighboring the beneficial allele; such genetic hitchhiking may result in a large area of homozygosity (i.e., a loss of diversity in a large area of a chromosome) due to a highly advantageous mutation and is referred to as a selective sweep.
- Students may be curious about how eumelanin and pheomelanin produce hair colors that range from blond to black, and why hair turns gray with age. Explain that the ratios of the two types of melanin pigments are responsible for all of the hair colors. For example, yellow (or blond) hair is produced by a small amount of brown eumelanin. Red hair results from a small amount of brown eumelanin mixed with mostly red pheomelanin. Gray or white hair result from a lack of melanin that occurs when melanocytes in hair follicles stop producing melanin as part of the aging process.
- Students may ask why, if melanin controls pigmentation of both skin and hair, there are people with light skin and dark hair and eyes or dark skin with light hair. The colors of a person’s skin, hair, and eyes are controlled by different sets of genes. Certain melanin-related genes get activated in one set of cells, like the cells that make hair, whereas other genes get activated in other cells, like the cells of the iris. Some genes affect pigmentation globally, as in some extreme forms of albinism, and certain mutations in the *MC1R* gene are associated with light skin and red hair. But for the most part, because the genes are not linked, pigmentation genes are inherited and function independently of one another. These genes are



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mostly independent of genes controlling other aspects of the human phenotype. Your students might be interested to learn that blond hair is found in parts of the South Pacific, such as the Solomon Islands, Vanatu, and Fiji (Figure 2). Indigenous Solomon Islanders have naturally dark skin, which is to be expected given the intense UV radiation in the South Pacific. However, a significant proportion has blond hair. Researchers have confirmed that the trait is not due to gene flow with Europeans but instead has its own origin among the indigenous population. The blond hair in people from the Solomon Islands is due to mutations in the *TYRP* gene that are unique to this group and occur at a frequency of 26% in the population.

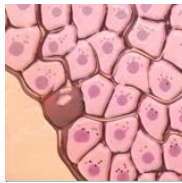
- Students may be confused about how we know that millions of years ago our ancestors were covered in hair and had pale skin. We don't have any fossilized skin from our ancestors. Researchers use comparative anatomical and genetic evidence from modern humans and modern African apes to construct what our ancestors were like. The human lineage originated in equatorial Africa 6–7 million years ago when it split from the lineage that led to our closest living relative, the chimpanzee. The last common ancestor modern humans shared with modern chimpanzees was not a chimpanzee but probably shared many features with modern African apes. All African apes have pale skin under their fur, and we can infer that the same was probably the case for the last common ancestor we shared with them.
- Humans are the only primates whose bodies are not completely covered in thick hair. Students may ask about the benefit of losing this hairy covering. The earliest fossils of the genus *Homo* (which is our genus) were found in Africa and date back to about 2 million years ago. From these fossils, we know that by this time our ancestors walked on two legs and would have been capable of walking long distances and even running. A running body produces a lot of heat. One hypothesis is that having less hair would have helped keep bodies cool when running and provided an advantage to these early humans. Over many generations, their bodies lost most of their hair and our ancestors became extensively covered in one type of sweat gland that makes dilute sweat. Walking long distances and running also suggest that early humans were spending less time in dense forests and more time in open areas with more intense sunlight. Ask your students why the evolution of more-heavily pigmented skin may have provided an advantage in this environment.
- Students may wonder if a suntan confers the same protective benefit as a darkly pigmented baseline skin color. Explain that while two similar skin tones (one natural, one tanned) may absorb and scatter damaging radiation in the same way at the surface, two notable differences are present. First, the UV-absorbing melanin in baseline (or constitutively) dark skin is present in cells deeper in the epidermis, rather than just near the surface as in temporarily tanned skin, and thus provides a greater overall protective benefit. Second, the continuous UV exposure that is required to maintain tanned skin can lead to premature aging due to the long-term damage to the structural proteins that give skin its strength and resiliency. Also explain that DNA damage occurs long before the tanning response can be observed and



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that recent evidence suggests that DNA damage may in fact be required to initiate the melanin production that causes tanning. After presenting the connection between cell damage and tanning, see if your students can infer why skin peels after a severe sunburn. (The reason is that the cells affected by UV become so damaged that they die, causing them to slough off to be replaced by new skin cells.)

- Dr. Jablonski suggests in the film that skin cancers may not have had a major impact on fitness. Why is that? It's true that more exposure to UV radiation leads to a higher risk of cancer, and pigmented skin protects against damage from UV. However, most skin cancers act later in life, after people are past reproductive age. By that time, most people would have had children and passed their genes on to them. This is why Dr. Jablonski argues that protection from skin cancer may not explain the evolution of darker skin color. Point out to students that this is an area of active scientific discussion and study. Some scientists have pointed out that melanomas can be fatal and some types, although rare, do strike younger people. Furthermore, other scientists argue that factors that affect people later in life can affect fitness. They note the importance of elders, including grandparents, for collecting food in hunter-gatherer societies, helping people achieve social status, and as sources of knowledge in preliterate societies. Dr. Jablonski, however, offered an alternative hypothesis for why darker skin is advantageous in high-UV environments. It is based on the observation that melanin not only protects DNA, it also protects an essential biological compound called folate (vitamin B9) from degrading. In females, folate is required for adequate egg cell production, implantation of the embryo in the uterus, and in the growth of the placenta. Once an embryo begins developing, folate protects the embryo from various abnormalities like spina bifida. In males, a deficiency in folate contributes to improper sperm development and infertility. Ask students how protecting folate from UV degradation would provide increased fitness in certain environments. Why is this a more likely explanation for the selective pressure on increased pigmentation in skin than skin cancer? Are the two explanations mutually exclusive?
- Students may be surprised to learn that vitamin D is synthesized in the body. Foods such as salmon and swordfish are high in vitamin D. Milk, some brands of cereal, orange juice, and yogurt are also fortified with vitamin D. However, many people don't get enough vitamin D from food alone and need to produce vitamin D in the body. Vitamin D synthesis in the body starts in the skin when a compound called 7-dehydrocholesterol (7-DHC) is converted into a compound called previtamin D in the presence of UV-B radiation. The previtamin D then undergoes further modification to become vitamin D. Vitamin D is essential for sufficient absorption of calcium and potassium to build and maintain our bones and to support our immune systems. A diet that includes foods that are naturally rich in vitamin D, coupled with a small amount of direct sun exposure (5–10 minutes per day on arms and legs, depending on latitude, altitude, and time of day) may be enough to provide the body with all the vitamin D it needs.
- As you show and discuss this film about human skin color, students may have questions and want to discuss race. When the biologist Carolus Linnaeus began to classify organisms in earnest in the early 1700s,



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he used skin color to identify what he thought were four different groups of people. Today, biologists recognize that there are differences among human populations both in terms of visible traits, like skin and eye color, and other traits, like susceptibility to disease. But when the full spectrum of variations across many traits is considered, there is no evidence for the existence of discrete human races. In other words, there are no set “packages” of traits that constitute a human race. For further background, consider visiting the [Race: Are We So Different?](http://www.understandingrace.org/home.html) website (<http://www.understandingrace.org/home.html>) from the American Anthropological Association. In addition, Dr. Jablonski has written several excellent articles and books on this topic; a recent interview with her appeared in *Nautilus* (Paulson, Steve, “About Your Skin: What You Should Know about Your Body’s Biggest Organ,” July 2, 2015, <http://nautil.us/issue/26/color/about-your-skin>).

ADDITIONAL BIOINTERACTIVE RESOURCES

Animation: [How We Get Our Skin Color](http://www.hhmi.org/biointeractive/how-we-get-our-skin-color) (<http://www.hhmi.org/biointeractive/how-we-get-our-skin-color>)

Narrated by Penn State University anthropologist Dr. Nina Jablonski, this engaging animation shows how human skin cells produce the pigment melanin, which gives skin its color.

Short Film: [Great Transitions: The Origin of Humans](http://www.hhmi.org/biointeractive/great-transitions-origin-humans) (<http://www.hhmi.org/biointeractive/great-transitions-origin-humans>)

Paleontologists have studied the fossil record of human evolution just as they have done for those of other major transitions—including the transition from fish to tetrapods and dinosaurs to birds. The HHMI short film *Great Transitions: The Origin of Humans* highlights the most important hominin fossil discoveries of the last 50 years and the insights they provide into human evolution, focusing on three key traits: bipedality, tool use, and larger brains.

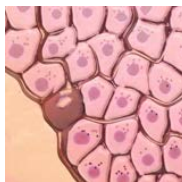
Holiday Lectures on Science: [Bones, Stones, and Genes: The Origin of Modern Humans](http://www.hhmi.org/biointeractive/bones-stones-and-genes-origin-modern-humans-0) (<http://www.hhmi.org/biointeractive/bones-stones-and-genes-origin-modern-humans-0>)

Where and when did humans arise? What distinguishes us from other species? Did our distant ancestors look and behave like us? In this Holiday Lecture series from 2011, leading scientists Dr. John Shea of Stony Brook University, Dr. Sarah Tishkoff of the University of Pennsylvania, and Dr. Tim White of the University of California, Berkeley, guide us on a global exploration spanning millions of years to illuminate the rise of modern humans.

Short Film: [The Making of the Fittest: Natural Selection and Adaptation](http://www.hhmi.org/biointeractive/making-fittest-natural-selection-and-adaptation) (<http://www.hhmi.org/biointeractive/making-fittest-natural-selection-and-adaptation>)

The short film focuses on the effects of natural selection on coat-color change in rock pocket mouse populations and the genes responsible for those differences. Several of the associated classroom resources discuss changes specific to the *MC1R* gene.

Additional resources on the biology of skin color may be found on the Smithsonian Institution website at <http://humanorigins.si.edu/education/teaching-evolution-through-human-examples>.



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USING THE QUIZ

We designed the quiz as a summative assessment that probes students' understanding of the key concepts addressed in the *Biology of Skin Color* film (<http://www.hhmi.org/biointeractive/biology-skin-color>). However, some teachers use the quiz before and during the film to assess students' prior knowledge and to guide students as they watch the film. We encourage you to choose the use that best fits your learning objectives and your students' needs. Moreover, because the vocabulary and concepts are complex, we encourage you to modify the quiz (e.g., only ask some of the questions, explain complicated vocabulary for English learner students) as needed.

QUIZ AND ANSWERS

1. (Key Concept A) True / False. Biologists classify specific forms of traits as good or bad. For example, long tails in cats could be classified as good and short tails as bad. (Circle the correct response.)

False. Biologists do not assign a moral value, judgment, or statement of worth to particular traits, as this is outside of the domain of science. They may study the impact of traits on fitness, but even then the effect of a particular trait may have a positive impact on fitness in one environment but a negative effect on fitness in a different environment.

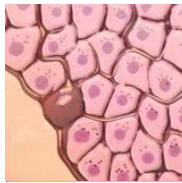
2. (Key Concept A) Explain the reasoning or evidence you used to answer Question 1.

After watching the film, students should realize that different shades of skin color have had different effects on fitness depending on where indigenous people lived. Dark skin had a positive effect on fitness in high-UV environments, whereas lighter skin had a positive effect on fitness in low- or variable UV environments. As Dr. Jablonski says in the film, "... biological traits aren't good or bad. They're features that have evolved because they enhance an organism's odds of surviving and passing on its genes."

3. (Key Concept D) If you travel north from the equator, what generally happens to the intensity of ultraviolet (UV) light?
 - a. The intensity increases.
 - b. The intensity decreases.**
 - c. The intensity stays the same.
 - d. It is impossible to predict.

The pattern of decreasing UV with increased latitude is clearly shown in the film at time mark 7:17.

4. (Key Concepts D and F) Who would you expect to be most at risk for developing the bone disease rickets?
 - a. Children born to mothers with dark skin, living far from the equator**
 - b. Adults with dark skin who live close to the equator
 - c. Children born to mothers with light skin, living close to the equator
 - d. Adults with light skin who live close to the equator
 - e. Anyone who eats a diet that includes a lot of fish



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5. (Key Concepts D and F) Explain the reasoning or evidence you used to answer Question 4.

Dark-skinned mothers living in high latitudes are at risk for vitamin D deficiency because environments far from the equator have lower levels of UV. If they do not produce enough vitamin D, they cannot pass it to their children in breast milk. Low levels of vitamin D interfere with the absorption of calcium and can lead to the bone disease rickets.

6. (Key Concept D) When Dr. Nina Jablonski describes her discovery of the UV data collected by NASA, a headline is visible that reads, "Ozone Depletion Raising Risk of Skin Cancer, Scientist Says." Use this headline and your understanding of what causes skin cancer to infer a beneficial feature of the ozone layer for humans. Why would a depleted ozone layer increase the risk of skin cancer?

The film discusses how UV damage to skin cell DNA can lead to cancer. Because ozone depletion raises the risk of skin cancer, one may infer that a depleted ozone layer is associated with a larger amount of UV reaching Earth's surface. The ozone layer is involved in blocking a substantial amount of the UV from the sun. An increase of UV in areas with depleted ozone would lead to more damage to skin cell DNA and ultimately higher rates of skin cancer.

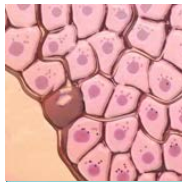
7. (Key Concepts B and H) Ultraviolet light can cause mutations and other damage within cells, which can hurt an individual's chance of surviving and leaving offspring. Some molecules can protect cells from damage by UV. The amount of these molecules is determined by genes. Within a population, some individuals make more of these UV-protection molecules than others. What do you predict would happen to the frequency of the genes that cause more of the molecules to be made in a population over time? Assume all other factors are equal.
- The frequency would increase because individuals need the genes.
 - The frequency would increase because individuals with the genes for more molecules would leave more offspring.**
 - The frequency would decrease because molecules are types of chemicals, and having more chemicals in the body is harmful.
 - The frequency would stay the same because populations do not change over time.

8. (Key Concepts B and H) Write down the evidence or reasoning you used to answer Question 7.

The problem states that increased UV can negatively affect a person's fitness. People with more of the molecules that protect cells from UV would leave relatively more offspring. Because the amount of these molecules is determined genetically, the number of individuals in the next generation with the genes that cause more of the molecules would increase. This is an example of natural selection.

9. (Key Concepts A, B, C, and F) Describe your ideas about why indigenous groups of people in different parts of the world have different skin colors from other groups of people.

In high-UV environments, darker skin offers protection from the damaging effects of UV radiation, especially to DNA and the valuable nutrient folate. In low-UV environments, there is a trade-off between protection from UV and the need for some UV absorption for the production of vitamin D. These low-UV environments favor lighter skin.



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10. (Key Concept D) Describe at least three different types of evidence that support your ideas for Question 9.

Evidence to support the claims in Question 9 could include

- **data from anthropology documenting the skin colors of indigenous people,**
- **data from physical science showing the pattern of UV across the globe,**
- **mathematically showing a relationship between skin color and UV levels,**
- **cell biology studies showing the effect of UV on DNA or folate,**
- **cell biology studies showing the protective effect of melanin, and**
- **data showing that in the past indigenous people with darker skin color in high-UV areas and people with lighter skin color in low-UV areas had higher fitness.**

Use the following scenario to answer Questions 11 and 12.

A biologist was studying two indigenous groups of people from different areas of the world. The first population was from equatorial Africa. The second population was from northern Europe. The biologist was studying a gene that affects skin color. The biologist examined the gene in 100 people from each population. She kept track of how many different forms (or alleles) of the gene she found in each population. The results are in the graph in Figure 1.

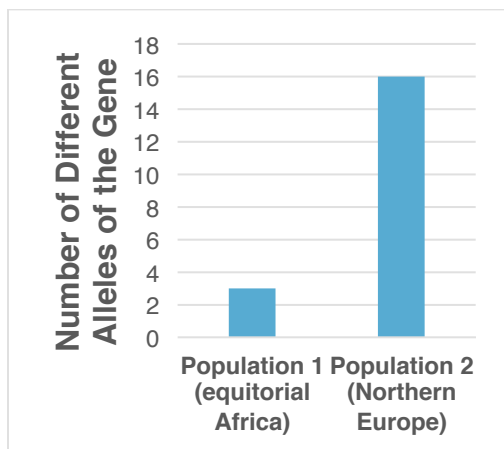


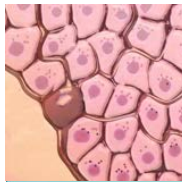
Figure 3. This graph appears as Figure 1 on the student quiz.

11. (Key Concept E) Describe the major pattern in the data in Figure 1.

In population 1, there are only three different alleles, whereas in population 2 there are 16 different alleles for the same gene.

12. (Key Concept E) Make a claim about the strength of stabilizing natural selection on this gene in the two populations. Use evidence from the graph (Figure 1) to support your claim.

In the film, Dr. Jablonski explains that “the absence of *MC1R* diversity in African populations indicates that, in that part of the world, there is strong negative selection against any alleles that would alter dark skin.” This means that there was a selective pressure to remove alleles from the population that



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caused a different skin color. The removal of harmful alleles is called **negative selection**. Another term for negative selection is “**stabilizing selection**.”

Using this reasoning, a valid claim is that **population 1 seems to have strong stabilizing selection**. The evidence is the much lower number of alleles in the population (which means a lower diversity). **Population 2 shows weaker stabilizing selection** as there are many different alleles for the gene.

13. (Key Concepts A, C, and F) Describe how having dark skin may have provided an advantage in survival and reproduction to people thousands of years ago in some places in the world but not in others.

As explained in Question 9, in high-UV environments, darker skin offers protection from the damaging effects of UV radiation, especially on DNA and the valuable nutrient folate. Thus, people with dark skin in these high-UV environments would have had an advantage in survival and reproduction. But in low-UV environments, there is a trade-off between protection from UV and the need for some UV absorption for the production of vitamin D. People with lighter skin in these environments would have higher rates of survival and reproduction.

14. (Key Concept A) Biologists sometimes say that “natural selection depends on the specific environment where a species lives.” What does this statement mean?

- a. If populations of a species are in different environments, traits that individuals need to meet their needs in each environment will appear.
- b. Traits can be helpful or harmful. If populations of a species are in different environments, some traits that are helpful in one environment might be harmful in another environment.**
- c. Traits are always either helpful or harmful, and the environment of a population does not matter. If populations of a species are in different environments, the same traits will always be helpful.
- d. Species were formed to perfectly match their environment. The traits of individuals in a species depend on the specific environment in which they were created.

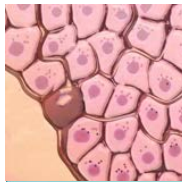
15. (Key Concept F) Describe how UV light is harmful to people but can also be necessary.

UV causes damage to DNA and to folate and can be harmful in both cases. However, UV is also needed to start the synthesis of vitamin D, which is necessary for bone and immune health.

16. (Key Concept G) How does the synthesis of melanin by melanocytes help these cells with their major function in skin?

One of the main functions of the skin is to act as a protective barrier against the harmful elements of the environment, such as ultraviolet radiation. Melanocytes manufacture melanosomes, which in turn synthesize melanin. Melanin protects the DNA of skin cells by forming protective coverings over the nucleus of skin cells. The absorption of UV by melanin protects folate in the circulatory system under the skin.

17. (Key Concept B) The graph in Figure 2 summarizes the age at which people are diagnosed with melanoma, the most serious form of skin cancer. Use the graph to explain why protection from skin cancer may not explain the strong selective pressure for dark skin in high-UV areas.



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The graph demonstrates that most people contract melanoma after their childbearing years. Therefore, most people who contract melanomas would have already had children and passed their genes on to them, reducing the strong selective pressure for darker skin. The role of skin cancer as a factor that may have influenced the evolution of skin color is still an area of active scientific discussion and study.

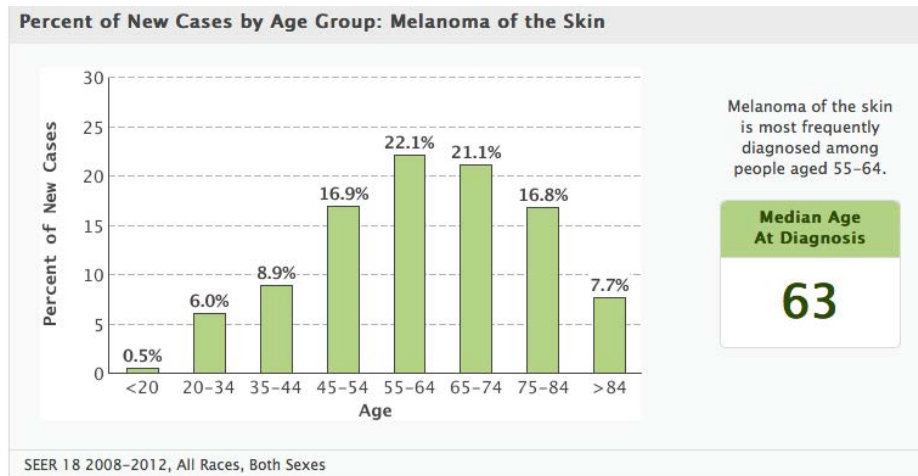


Figure 4. This graph appears as Figure 2 on the student quiz. (Source: National Cancer Institute's Surveillance, Epidemiology, and End Results Program <http://seer.cancer.gov/statfacts/html/melan.html>.)

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